

# SPECIFICATION

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## **Dynamic Prosthetic Foot with Multiple Load Points and Multiple Upper Sections**

### **Background of Invention**

[0001] Field of the invention

[0002] This invention relates, generally, to the art of prosthetics. More particularly, it relates to improvements in prosthetic feet.

[0003] Description of the prior art

[0004] During normal ambulation, the first part of a foot to contact the ground is the free end of the heel. This initial contact between heel and ground is known as the "heel strike." The free end of the heel is soft and thus cushions the heel strike to at least some extent. The hard bottom of the heel is the next part of the foot to strike the ground; its hardness allows it to support the entire weight of the body. The foot continues to rotate in the well-known way until the toes "push off" at the end of a step.

[0005] Early prosthetic feet were quite rigid and provided little or no cushion to the impact on the ground at the moment of "heel strike" and little or no elastic response at "push off." The shock of impact was thus transmitted directly to the skeletal structure of the user, and the lack of elastic response forced an unnatural gait.

[0006] Perhaps the earliest prosthetic foot that provided an elastic response at heel strike and push off is disclosed in U.S. patent No. 4,547,913 to Phillips, assigned to Flex Foot, Inc. Multiple versions of that device have been developed. The original version is formed of a carbon fiber epoxy matrix consisting of a one-piece combination pylon upper and a one-piece sole. Mechanical fasteners interconnect the upper and the sole.

In a second embodiment, the pylon is a round hollow tube and is connected by mechanical fasteners to a rectangular-shaped upper. A third version is like the first except that a standard Sach<sup>®</sup> foot adapter is employed to connect a standard prosthetic pylon. A fourth version is like the third but has a slightly different geometry. In a fifth version, an elastomeric glue connects the upper and the sole. In additional embodiments, leaf springs or hydraulic cylinders are incorporated into the prosthetic foot.

[0007] Although the developments in the art since the mid 1980s have significantly advanced the technology of prosthetic feet, the known prosthetic feet still provide little or no heel elasticity in a direction parallel to the ground. Instead, they provide elastic response in a vertical plane. Thus, although the impact at heel strike is reduced *vis a vis* the pre-1980's prosthetic feet, the reduced impact is transmitted vertically to the skeletal structure of the user, and the elastic response in a vertical plane causes a four to six millimeter bounce at heel strike. This vertical response causes an unnatural walk because a healthy human heel is soft at the back or free end where heel strike occurs and is hard on the bottom so that it can support the entire weight of the body. Thus, the normal gait of a human includes a rolling motion as the back of the heel strikes the ground; there is no vertical motion causing the heel to bounce upon ground impact. Accordingly, there remains a need for a prosthetic foot that provides substantial heel elasticity in a direction parallel to the ground.

[0008] A healthy human foot rolls on the lateral part of the foot during ambulation. The medial part of the foot provides a cushion and the force required at push off. Thus, there is a smooth transition from heel strike to push off, with no vertical dynamic response of the type that could cause the foot to bounce. Prosthetic feet of the type heretofore known, however, do not provide a smooth transition from heel strike to push off. This lack of a smooth transition produces what is known in the industry as a "flat spot." The presence of a flat spot between heel strike and push off produces an unnatural gait.

[0009] More particularly, the dynamic response is primarily vertical at the heel and the toe of a prosthetic foot. There is little or no component of the dynamic response in a horizontal plane as present in a healthy natural foot. The absence of dynamic

response in a horizontal plane results in a step like motion going from an elastic vertical motion at heel strike to little or no support at mid-stance (the flat spot), and then again to an elastic vertical motion at push off.

[0010] There is a need, therefore, for a prosthetic foot having a dynamic response in a horizontal plane during heel strike, that provides a smooth transition between heel strike and push off to eliminate the flat spot, and that provides a dynamic response in a horizontal plane during push off.

[0011] The human foot provides a more rigid support laterally than medially. This design is advantageous because when an instability occurs, the weight of the person shifts from the rigid outer or lateral edge of the foot to the less rigid inner or medial edge. In this way, the prosthetic foot takes advantage of the presence of the natural foot, *i.e.*, the lateral-to-medial motion experienced at the moment of an instability shifts additional support duties to the natural foot. One major drawback of the heretofore known prosthetic feet is the fact that such feet provide an exactly vertical response during ambulation with no component toward the medial section of the foot. Thus, if an instability in one foot urges the person to fall away from the natural foot, there is no shift of weight toward the medial part of the prosthetic foot as would occur in a natural foot, and the likelihood of a fall is substantially increased.

[0012] A prosthetic foot is therefore needed that has differentiated medial and lateral stiffness so that it can respond to instabilities in much the same way as a natural foot.

[0013] However, in view of the prior art considered as a whole at the time the present invention was made, it was not obvious to those of ordinary skill in the pertinent art how the identified needs could be fulfilled.

## Summary of Invention

[0014] The long-standing but heretofore unfulfilled need for a dynamic prosthetic foot is now met by a new, useful, and nonobvious dynamic prosthetic foot having multiple load points and multiple upper sections. The novel prosthetic foot includes a sole having a heel end and a toe end and multiple upper sections that overlie the sole. The upper sections are formed by longitudinally splitting an upper member having a heel end, a toe end, and a pair of flat, transversely spaced apart, pylon supports formed in

its heel end. The pylon supports include a lateral pylon support and a medial pylon support.

[0015] The heel end of the upper member has a gradual ninety degree bend formed therein so that the pylon supports are disposed substantially perpendicular to the sole. The heel end of the upper member separates from the sole along a parting line that is transverse to a longitudinal axis of the prosthetic foot.

[0016] A slot is formed in the heel end of the upper member, substantially coincident with the longitudinal axis of the prosthetic foot. The slot extends from an uppermost end of the heel end of the upper member to a preselected point that is about two-thirds of the way from the heel of the sole to the toe of the sole. Forces acting on the lateral pylon support are substantially confined to the lateral section of the upper member and forces acting on the medial pylon support are substantially confined to the medial section of the upper member.

[0017] The lateral pylon support and the lateral section of the upper member have greater thickness than the medial pylon support and the medial section of the upper member. The greater thickness imparts greater stiffness so that forces applied to the lateral pylon support and the medial pylon support are transferred more to the medial pylon support and the medial section of the upper member than to the lateral pylon support and the lateral section of the upper member, thereby mimicking the reaction of a natural foot to forces applied thereto.

[0018] The sole has a first convexity formed in the heel end that performs the function of the bottom of a natural heel. The sole has a concavity longitudinally spaced from the first convexity, said concavity performing the function of a natural arch. The sole has a second convexity longitudinally spaced from the concavity, said second convexity performing the function of the ball of a natural foot. The transverse parting line where the heel end separates from the sole is in juxtaposition with a bight of the concavity.

[0019] The slot that divides the upper member into two upper sections has a heel end that is in open communication with the respective free ends of the lateral and medial pylons. The leading end of the slot extends to the point of inflection where the concavity formed in the sole meets the second convexity.

- [0020] In an alternative embodiment, the upper member and sole are formed integrally with one another between the transverse parting line and the toe of the prosthetic foot.
- [0021] In a second embodiment, the pylon supports and connectors are supplanted by elongate pylons.
- [0022] An important object of this invention is to provide a prosthetic foot having a smooth transition from heel strike to push off.
- [0023] Yet another object is to provide a prosthetic foot having differentiated medial and lateral stiffness so that an instability tends to shift weight from the lateral edge of the prosthetic foot to the medial edge thereof, just as in a natural foot.
- [0024] Another object is to provide a prosthetic foot having two pylon supports or two pylons to improve the rollover motion. Another object is to provide a prosthetic foot having multiple pylon supports or pylons, said multiple pylon supports or pylons inherently exhibiting lower torsional stiffness than a single tube-type pylon support or pylon.
- [0025] A further object is to provide a prosthetic foot that flexes in medial lateral planes without having any moving surfaces that wear and make noises when said surfaces move relative to one another other, such as in a bushing or in a hinge.
- [0026] These and other important objects, advantages, and features of the invention will become clear as this description proceeds.
- [0027] The invention accordingly comprises the features of construction, combination of elements, and arrangement of parts that will be exemplified in the description set forth hereinafter and the scope of the invention will be indicated in the claims.

### **Brief Description of Drawings**

- [0028] For a fuller understanding of the nature and objects of the invention, reference should be made to the following detailed description, taken in connection with the accompanying drawings, in which:
- [0029] Fig. 1 is a top plan view of a prosthetic foot with multiple load points and multiple

upper members having truncate pylon supports and connectors;

- [0030] Fig. 2 is a side elevational view thereof;
- [0031] Fig. 3 is a perspective view thereof;
- [0032] Fig. 4 is a top plan view of a second embodiment of the prosthetic foot of Fig. 1;
- [0033] Fig. 5 is a side elevational view of said Fig. 4 second embodiment;
- [0034] Fig. 6 is a perspective view of said Fig. 4 second embodiment;
- [0035] Fig. 7 is a top plan view of a prosthetic foot with multiple load points and multiple upper sections and having elongate pylons;
- [0036] Fig. 8 is a side elevational view thereof;
- [0037] Fig. 9 is a perspective view thereof;
- [0038] Fig. 10 is a top plan view of a second embodiment of the prosthetic foot of Fig. 7;
- [0039] Fig. 11 is a side elevational view of said Fig. 10 second embodiment;
- [0040] Fig. 12 is a perspective view of said Fig. 10 second embodiment;
- [0041] Fig. 13 is a perspective view of the elongate pylons embodiment when attached to a socket;
- [0042] Fig. 14 is a perspective view of the elongate pylons embodiment and further depicting connector means, in exploded form, for connecting said elongate pylons to a socket;
- [0043] Fig. 15A is an exploded first perspective view of said connector means;
- [0044] Fig. 15B is an exploded second perspective view of said connector means;
- [0045] Fig. 15C is a first perspective view of a pyramid-receiving connector; and
- [0046] Fig. 15D is a second perspective view of said pyramid-receiving connector.

## Detailed Description

[0049] Upper member 30 includes a pair of flat, transversely spaced apart, pylon supports 32, 34 that are separated from one another by longitudinally extending elongate slot 36. Lateral pylon support 32 has a greater thickness than medial pylon support 34 as indicated in Figs. 1 and 3. A gradual ninety degree bend formed in substantially horizontal upper member 30 near its heel end forms said substantially vertical pylon supports 32, 34.

[0051] The length of elongate slot 36 is sufficient to substantially divide upper member 30 into upper sections 30a and 30b. Each of said sections thus responds to forces appearing at the heel end of foot 10 in substantially independent response. Moreover, since slot 36 extends to inflection point 37, said upper sections 30a and 30b also respond substantially independently to forces appearing about mid-length of foot 10, *i.e.*, those forces appearing about mid-gait of a stride. The greater thickness and

thus greater stiffness of lateral pylon support 32 ensures that instabilities appearing on foot 10 will be shifted in a medial direction, just like a natural foot. Slot 36 enables lateral pylon support 32 to respond to instabilities substantially independently of medial pylon support 34, and *vice versa* . In other words, forces transmitted from the lateral side of the prosthetic foot are substantially attenuated when transmitted to the medial side of the foot, and *vice versa* .

[0052] Pylon connectors 40, 42 are attached to pylon supports 32, 34, respectively, preferably on a trailing (heel) side thereof, and an elongate pylon, not shown in Figs. 1-3, is then engaged to each pylon connector.

[0053] Pylon supports 32, 34 are curved as depicted so that they gradually join upper members 30a and 30b at a transverse parting line 44 that is about mid-length of arch concavity 20, *i.e.* , at the bight of said concavity. Upper members 30a and 30b overlie and abut sole 12 from transverse parting line 44 to toe end 46 thereof. The respective thickness of upper members 30 and 30b gradually decrease as depicted as they extend from said point 44 to said toe end. The combined thickness of sole 12 and upper member 30 at said toe end is substantially the same as the thickness of the heel end 14 of sole 12. The elastic response of said heel and toe ends of said sole 12 are thus controlled by the thickness of the sole and upper member to provide differentiating elastic response for patients of differing weights and/or activity levels.

[0054] The alternative embodiment of Figs. 4-6 is like the embodiment of Figs. 1-3 in all respects except that sole 12 and upper member 30, divided into upper sections 30a, 30b in Figs. 1-3, are of unitary construction in the embodiment of Figs. 4-6.

[0055] The embodiment of Figs. 7-9 differs from the embodiment of Figs. 1-3 in that pylon supports 32, 34 are supplanted by elongate pylons 32a, 34a having a length of about twenty inches (20"). This eliminates the need for pylon connectors 40, 42. Pylons 32a, 34a are cut to size by the prosthetist when the prosthesis is fitted onto the patient.

[0056] The embodiment of Figs. 10-12 similarly differs from the embodiment of Figs. 4-6 in that pylon supports 32, 34 are supplanted by elongate pylons 32a, 34a having a length of about twenty inches (20"). This eliminates the need for pylon connectors 40,



42.

[0057] Moreover, sole 12 and upper member 30, divided into upper sections 30a, 30b in Figs. 7-9, are of unitary construction in the embodiment of Figs. 10-12.

[0058] Fig. 13 depicts the novel structure when equipped with elongate pylons 32a, 34a.

[0059] After pylons 32a, 34a have been cut to a desired length, the prosthetist has several options by which the pylons may be connected to prosthetic socket 48. Pylons 32a, 34a may be laminated into prosthetic socket 48 as illustrated in said Fig. 13. This forms a permanent connection between pylons 32a, 34a and socket 48.

[0060] A second option includes the use of a commercially available pyramid connector 50 as depicted in Fig. 14. Such pyramid connectors have been in use for fifty or so years. Pyramid connector 50 includes upper part 52 and lower part 54 that depends from the upper part. Upper part 52 is attached to the lowermost or distal end of socket 48. A hollow pyramid-receiving connector 56 has an open upper end 58 that receives lower part 54 of pyramid connector 50 and an open lower end 60 that receives the respective uppermost ends of pylons 32a, 34a. Lower end 54 of pyramid connector 50 and the respective upper ends of pylons 32a, 34a are captured in said hollow pyramid-receiving connector 56 by a plurality of set screws, collectively denoted 62.

[0061] Pyramid connector 52 and pyramid-receiving connector 56 are employed to enable adjustment of the angle of pylons 32a, 34a so that prosthetic foot 10 falls in the correct medial/lateral and anterior/posterior planes, as perhaps best understood by making reference to Fig. 14.

[0062] A third option available to the prosthetist after cutting the pylons to their correct length is to laminate the pylons to an unillustrated component and to attach that component to the socket.

[0063] Figs. 15A and 15B provide a more detailed perspective view of pyramid connector 50 and pyramid-receiving connector 56. Figs. 15C and 15D provide a more detailed perspective view of pyramid-receiving connector 56.

[0064] The thickness of upper member 30a is substantially different from the thickness

of upper member 30b to provide a controlled elastic response. More specifically, the different thickness shifts loads from the lateral section to the medial section. This performs the function of eliminating the flat spot of earlier prosthetic feet because such construction provides a smooth transition from heel strike to push off. Moreover, the bifurcated construction of pylon supports 32, 34 (Figs. 1-6) or pylons 32a, 34a (Figs. 7-12) and the greater thickness of lateral pylon support 32 or pylon 32a and upper member 30a enhance the stability of the user because said greater thickness serves to shift the weight of the user toward the medial side of the foot and thus harnesses the stabilizing power of the sound foot that opposes the prosthetic foot.

[0065] The novel structure further enhances the medial lateral stability, the torsional flex, and the anisotropic stiffness of prosthetic foot 10. An anisotropic foot does not exhibit isotropocity. *i.e.*, an anisotropic prosthetic foot advantageously exhibits properties with different values when measured in different directions.

[0066] Two pylons provide advantages over single pylon structures, especially when torsional characteristics are considered. Some torsion in the shin, and more precisely torsion that can be controlled by the thickness and geometry of the cross section, is advantageous over totally rigid pylons. For example, such torsion would prove advantageous when playing a round of golf.

[0067] It is also very significant to note that the novel prosthetic foot can flex in the medial lateral plane in the substantial absence of parts that move relative to one another.

[0068] It will thus be seen that the objects set forth above, and those made apparent from the foregoing description, are efficiently attained. Since certain changes may be made in the above construction without departing from the scope of the invention, it is intended that all matters contained in the foregoing description or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

[0069] It is also to be understood that the following claims are intended to cover all of the generic and specific features of the invention herein described, and all statements of the scope of the invention that, as a matter of language, might be said to fall therebetween.

[0070] Now that the invention has been described,